OCEAN TRACKING NETWORK

IMOS Integrated Marine Observing System

Towards a best practice in acoustic telemetry mooring design

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Photo: Nicolas Winkler Photography, courtesy of the Ocean Tracking Network

Executive summary

This document presents trialled and tested, best practice methods for the subsea deployment of acoustic telemetry equipment developed by two of the world's longest operating animal telemetry networks, the Ocean Tracking Network (OTN, www.oceantrackingnetwork.org) and the Animal Tracking Facility of Australia's Integrated Marine Observing System (IMOS, https://imos.org.au/facility/animal-tracking/acoustic-telemetry).

Over the past two decades, these two telemetry networks have implemented and refined methods for the safe and optimal deployment of subsea equipment in their respective regions of operation and in diverse marine systems (i.e. from estuarine coastal sites to deep offshore waters). Drawing on the lessons learned, this document presents the rationales for particular mooring configurations and deployments, as well as a decision tree to aid users in determining the optimal mooring design for their sites. A selection of case studies spanning estuarine, coastal and offshore marine environments is provided to exemplify the mooring design process.

The objectives of this document are to inform safe field operations, optimum resource use and generation of the highest-quality acoustic telemetry data.

This is intended to be a living document, and will be updated and refined as new robust advances in the deployment of acoustic telemetry equipment are made. We encourage interested researchers to submit an Issue via the dedicated Github page https://github.com/ocean-tracking-network/OBPS-moorings to discuss their respective approaches, and help refine the contents of this document.

Disclaimer: This document is created from the robust experiences of telemetry field teams operating for 10+ years, but fault in a mooring design or lack of safety precautions taken from this document has no liability for the writers.

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1 Background and goals

1.1 Purpose

In recent decades, the use of passive acoustic telemetry to monitor the occurrence and movements of aquatic animals has rapidly expanded across the globe (Alos et al. 2022; Hussey et al. 2015; Matley et al. 2022). The approach has been widely applied to a range of species spanning invertebrates, finfish, elasmobranchs, reptilians and marine mammals, in systems ranging from inland lakes and rivers to the high seas, and from polar to tropical regions (e.g. Brodie et al. 2018; Hussey et al. 2015; Lennox et al. 2023; Lowerre-Barbieri et al. 2021; Udyawer et al. 2023).

Animal movements have been linked to a variety of activities necessary for survival, such as foraging, reproduction, their respective physiological limitations or other essential habitat services (e.g. cleaning) (e.g. Bonfil et al. 2005; Hawkes et al. 2007; Heyman et al. 2001; Jaine et al. 2012, 2014; Schofield et al. 2009). While land-based animal telemetry science has benefited from Global Positioning System (GPS) and radio technology approaches for decades, limitations associated with underwater positioning and data transmission require a different type of technology to track aquatic animals. Acoustic telemetry, involving the use of animal-borne acoustic transmitters and moored receivers, has become a powerful tool for aquatic animal tracking (Hussey et al. 2015; Matley et al. 2021).

One of the key limitations of acoustic telemetry is signal propagation through the water, which can be influenced by a plethora of environmental factors and results in different outcomes depending on the study setting (Heupel et al. 2008; Huveneers et al. 2016; Kessel et al. 2014; Klinard et al. 2019; Simpfendorfer et al. 2008). As a result, the detection range of acoustic receivers can vary greatly, from tens of metres to ~1 km from its moored location. As such, it is important to configure receiver arrays to collect optimal quality data based on the known technological limitations, study design and research objectives. Doing so typically requires deploying receivers in a variety of environmental settings (e.g. shallow coastal waters, deeper shelf waters), sometimes in collaboration with research partners who deploy and maintain infrastructure and share the resulting data.

The increased uptake of acoustic telemetry technology by researchers around the globe and its systematic use by broad-scale, coordinated animal telemetry networks, has stimulated the development of best practices methods within the user community. If applied correctly, these best practices can help to ensure optimal equipment performance, high quality data collection, as well as safe, cost-efficient operations and maintenance.

1.2 Designing an acousitc telemetry mooring

While there are many factors to consider when designing an acoustic telemetry mooring (figure 1), keeping the following three things in mind will help guide successful mooring design, deployment and maintenance:

1. **Simplicity**. Generally, the more complex the mooring design, the more potential points of failure, especially when deploying equipment for extended periods.

2. **Practicality.** Consider the minimum requirements of a mooring to be safely deployed in that particular environment, to reduce resource use, environmental impact, logistical requirements, and manual handling risks.

3. **Safety.** Consider your deployment and recovery protocols carefully to reduce personnel risks of injury from manual handling. Always read the relevant safety warnings for any materials included in the mooring.

The key decision making variables for acoustic telemetry mooring design are summarised in figure 1 below.

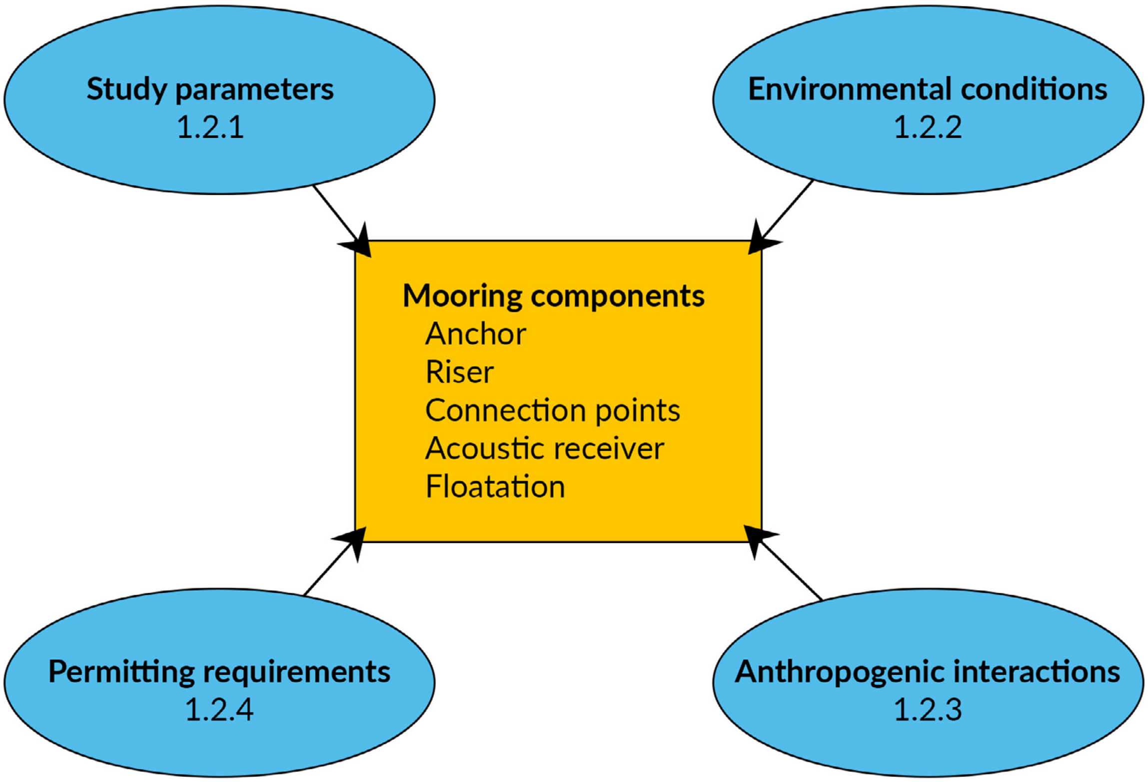

Figure 1: Overview of the decision variables for acoustic telemetry mooring design.

1.2.1 Study parameters

In the early stages of designing an acoustic tracking study, it is critical to consider:

- **Study aims and objectives:** For example, a fine-scale tracking project (i.e. high temporal and spatial resolution of animal movements) will have different priorities compared to a site-specific presence-absence study - the objectives will impact the number of moorings required and their placement within the study area.

- **Equipment:** Consult with equipment manufacturers and/or experienced users of telemetry equipment during the study design stage to ensure that the right type and number of acoustic receivers are selected to adequately answer the study questions.

- **Range testing:** Range testing procedures are beyond the scope of this document, but are key to assessing the study plan. It is also critically important to understand where and how you are proposing to deploy the equipment at this stage of the study planning, as environmental conditions will impact receiver performance.

- **Study duration:** Understanding how long a mooring will need to remain underwater is essential when choosing appropriate mooring hardware that can resist corrosion and wear.

- **Resource availability:**

    - **Budget:** Consider not only the upfront cost of purchasing equipment and mooring components, but also the running operational and maintenance costs for the life of the study, including the potential need to replace lost or damaged equipment.

    - **Personnel and training:** People play a critical role in the success of any project. Collaborate with and employ people who have the skills, experience and motivation to contribute to the project in the capacity required.

    - **Vessels:** The availability of suitable vessels may limit study design and mooring choice. Understand the vessel requirements for the deployment and retrieval of your moorings, and adjust project plans accordingly. These include but are not limited to:

        - Crew requirements;
        - Maximum capacity;
        - Maximum load;
        - Vessel size and/or available deck space;
        - Docking requirements and accessibility for mobilization and demobilization;
        - Specialized deployment/retrieval equipment (e.g. winch or A-frame);
        - The ability to safely access the study area in a variety of weather conditions.

1.2.2 Environmental conditions

The conditions of the study environment must be evaluated in the planning stages, as this will determine many components of the mooring design and efficacy. These include but are not limited to:

- **Depth:** Depth determines the mooring accessibility. Use bathymetry maps to assist in plotting potential mooring locations most suitable for the study.

- **Current, tide, and wave action:** Areas with high wave energy may not be suitable for certain mooring components. For example, a sheltered area, like a bay or lake with minimal tide will allow for a simplistic mooring design. By contrast, deployments in high energy or unsheltered environments, such as areas subject to intense wave action or sites with large tides or currents, require more robust mooring components. The chosen mooring design should be built to withstand the most extreme environmental conditions possible to occur during the entirety of deployment, including weather events.

- **Substrate:** Deployments on different substrate types will require different mooring approaches. Moorings used on rocky reefs may not be suitable for areas characterised by soft sediment or fragile corals. The correct mooring provides the most efficient operation of the equipment while minimising mooring footprint in the environment and maximising deployment success over time.
- **Physical obstructions:** It is important that the mooring design allows the hydrophone to be clear of any physical obstructions that may impair the detection range (e.g. sandbars, coastlines or underwater structures).
  - **Ice:** can be a consideration when working in polar and boreal environments. Movement of ice can result in the destruction of surface floats by grabbing and dragging moorings to a different location. In addition, in some cases ice buildup on the instrumentation package can exceed the mooring's weight, resulting in the mooring drifting upwards through the water column.
- **Ambient noise:** Understanding the ambient noise patterns of your chosen study environment will help guide the choice of appropriate deployment locations, spacing requirements between receivers and increase overall study success. Range testing can be used to help characterize the ambient noise for the study area (see section 1.2.1 Study parameters).

1.2.3 Anthropogenic interactions

Fishing activities at sites where equipment is deployed can result in equipment being displaced and subsequently lost. It is highly recommended to consult with fisheries management agencies, as well as with the licensed fishers in the deployment area, to cultivate a diverse network of knowledgeable and supportive local operators early in the study planning phase. These individuals can provide insight into seasonality of certain species of interest, the type of fishing equipment used, identification of site hazards, mitigation actions or processes for interference and key knowledge about local conditions like bathymetric data. It's important to note that forging a positive relationship and sharing information surrounding your research goals with local stakeholders can facilitate the recovery and return of equipment should a gear conflict arise with other users of the area. Engaging communities by chartering local vessels for equipment maintenance is highly advised when the vessels meet necessary safety and operating standards.

Theft, vandalism or disturbance by curious parties can also be an important consideration in some areas. When these concerns are significant, you may want to consider the use of a subsurface equipped with an acoustic release (see section 2.4.2 for subsurface floatation considerations). Contacting the appropriate authorities for the inclusion of your deployed moorings on navigation or oceanographic maps, especially for long term deployments, can be helpful for fisheries avoidance. Ensure that all pieces of equipment are well labelled, using marine-safe markers or waterproof stickers, with contact details, so that equipment can be returned should it break free of its mooring.

1.2.4 Permitting requirements

Once locations for equipment deployment are selected, permitting requirements should be identified. Permits are often linked to other activity in the desired deployment areas like fishing or designated conservation areas such as marine protected areas (MPAs). The application and approval process associated with permitting can often take longer than anticipated and delay an otherwise ready-to-deploy study, so begin the process as early as is practical. Permits may stipulate conditions that influence mooring design or servicing time frames, therefore such details should be clarified before investing capital on receivers and mooring hardware.

1.2.5 Deciding on mooring components

An acoustic receiver mooring can be thought of in terms of its main components in order to ensure the final design is appropriate for the study environment. Some of these components may not be needed depending on the selected mooring design and the characteristics of the study site. For example, in sites where it is possible to safely deploy and service a mooring with a surface buoy or via SCUBA, grappling lines, or acoustic releases may not be needed.

The main components of an acoustic receiver mooring typically include:

- Anchor (see Mooring components 2.1)
- Riser (see Mooring components 2.2)
- Connection points
- Acoustic receiver (see Mooring components 2.3)
- Floatation (see Mooring components 2.4)

2 Mooring components

2.1 Anchor

All moorings require a benthic fastening or mooring point that maintains them at a fixed location and ensures consistency of data collection. The anchor must:

- Be heavy enough that it reliably counters the buoyancy of the rest of the mooring for the duration of the deployment (e.g., during storm events);
- Be connected to the rest of the mooring in a reliable manner that will not cause damage or entanglement during deployment;
- Be safe to handle, and

- Allow successful retrieval of the acoustic receiver and associated instrument packages when desired.

If the anchor weight is insufficient and the mooring drifts or drags across the seabed, it can impact the validity of the study, cause retrieval challenges, and - in a worst-case scenario - result in environmental damage and mooring loss, including the data that it was collecting. Refer to section 2.4 for more details on floatation.

When deciding on an anchor type, it is especially important to consider the following variables:

- **Total mooring length:** A longer mooring generally requires a heavier anchor, because there will naturally be more drag on the line with water movement from currents and tides.
- **Current and tide movements, storm surges:** More force from water movement will require a heavier anchor to counteract. Storm surges in coastal locations are also potentially a key factor, depending on the seasonal timing of a deployment. If the area is known for high wind and sea swells, the weight of the anchor for the mooring should be increased accordingly, especially at shallower depths where there is more impact from wave energy. Refer to case study 6.
- **Fishing pressure:** If it is necessary to deploy equipment in a location with a significant risk of fisheries interactions and/or potential entanglement or collision with fishing gear, the goal would be to have your mooring unharmed and unmoved, which would start with a secure and heavy fixation point.
- **Mooring fate:** Understanding whether an anchor will or can be left at the study site ("sacrificial anchors"), or must be recovered upon completion of a study, is

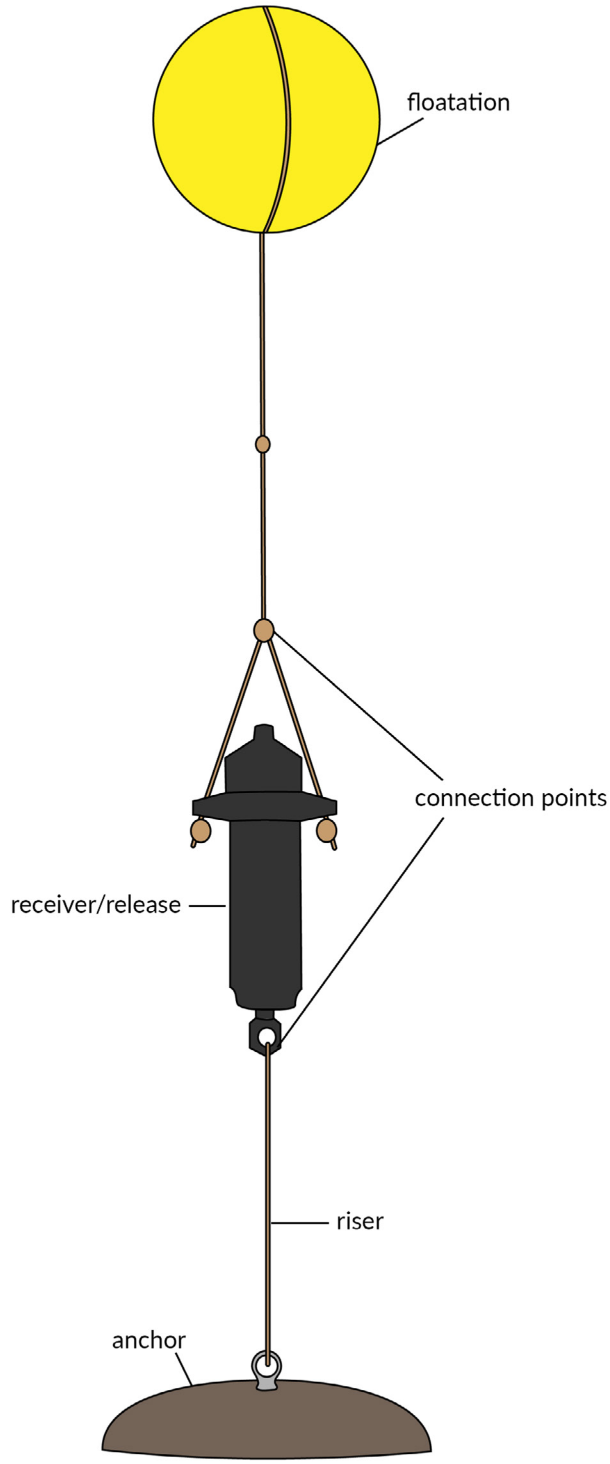

Figure 2: Generalised design of an acoustic receiver mooring and key components (figure is not to scale).

a key consideration for the overall mooring design. The heavier the anchor used for the mooring and the deeper the desired location, the more difficult it is to retrieve the anchor upon study completion. Deep and heavy anchors may require a larger and more costly vessel for retrieval and may not be permitted by the local authorities, local stakeholders and/or traditional owners (see section 1.2.4).

Several common anchor types are outlined below. Refer to the end of the section for a summary table.

2.1.1 Pre-Existing Structures

In the most straightforward of all anchor options, a receiver can simply be fastened to a pre-existing structure using cable ties, chain, or any other sturdy material and attachment method.

Example structures include, but are not limited to, natural rock or reef formations, wharf pylons, aquaculture farm infrastructure, shipwrecks, or oceanographic buoys. A star picket, also referred to as a steel fence post or T-post, is suitable for some substrates (see case study 1, figure 6b). The star picket acts as an anchoring point that is installed by wedging it into a rocky reef structure that can also support a receiver.

It is important to ensure that both the structure and connection method are robust enough to support the receiver and withstand eventual current and surge during the planned deployment period. Regardless of the method used, ensuring that the receiver hydrophone and its detection range are unobstructed is a key consideration that requires particular attention for optimal receiver performance. It may be prudent to contact the operator responsible for the structure (wharf manager, buoy tenders) to ensure they will not remove the equipment, and to receive their advice on how to avoid having the receiver tampered with by other users of the structure.

2.1.2 Sand Screws

A sand screw, or sand auger, can be used when the substrate is soft (sand or mud) and environmental energy is low. Sand screws require diver deployment and recovery but cause minimal long-term disturbance to the study environment, have been successfully deployed for extended periods in multiple studies, and can be easily removed once the work is completed.

2.1.3 Concrete Anchors

Concrete is less dense and more porous than metal, making it more buoyant and weighing less in seawater than in air. Concrete anchors therefore will often need to be larger and heavier on land than a metal anchor equivalent, which can pose a challenge for manual handling.

Regardless, concrete can be beneficial in a mooring due to its robustness, accessibility, and longevity. Concrete anchors are typically used for shallow water moorings (<30 m) in low-current environments where the receiver can be replaced by divers, leaving the anchor in place. Aggregate of rock or scrap metal can also be added to the anchor prior to pouring the concrete to increase anchor density or can be used as an attachment point to the rest of the mooring after pouring (see ‘Mastaba’, case study 1, figure 6a).

Concrete anchors can be custom built to accommodate a range of receiver sizes; for example, a simple design consisting of a concrete base with a star picket secured at 90 degrees to the anchor has had great success in Australia over a decade of deployments. A receiver is secured to the picket with cable ties and bolt, and can be switched out by divers as often as required. Alternatively, a PVC pipe can be integrated into a concrete base to hold a variety of receiver sizes - refer to case study 1 for more details.

Concrete can be moulded into different shapes to best suit the environment and deployment purposes. The determined shape can minimize the risk of entanglement or fisheries interaction. From an environmental perspective, concrete anchors can be designed with a similar structure to rocky bottoms which can promote growth, like an artificial reef (Lemoine et al. 2019). Additionally, there are green-concrete options that utilise waste materials which may be a more sustainable choice (Suhendro 2014).

A key challenge with concrete moorings is their tendency to get overturned in high energy environments. In high-current conditions, a chain anchor may be more appropriate. See section 2.1.4.2 and refer to table 1 for more details.

2.1.4 Metal Anchors

Various anchors designed for specific applications can be cast out of metal. In locations where sacrificial anchors are allowed, metal anchors can also serve as a structure for artificial reefs as they are stable in high energy environments and promote recruitment for many organisms in the geographical area of deployment (Lemoine et al. 2019). Various metals can be used for anchors, with some being more reactive in sea water to chemical or galvanic corrosion. See figure 4 for notes on corrosion and galvanic scales.

2.1.4.1 Iron

It is recommended to use iron anchors, or a similarly dense material, for deployments lasting several years or in deep (>100 m) or volatile locations. Iron can support marine growth and will eventually oxidize over extended periods of time, therefore it is considered less harmful to the environment if the anchor is sacrificial. Iron corrodes more in comparison to other metals, but this happens over extended periods of time. Iron anchors can be purpose-cast disc anchors or scrap metal bundles such as boom chain, train wheels, etc. and can be sourced at a variety of weights and sizes. Iron is one of the more cost-effective metals to use.

2.1.4.2 Steel

Steel is a common option for anchor material, either in the form of heavy link chain, or as single pieces. Scrap metal steel can be a relatively cost effective option, depending on the area where they are sourced. Chain may be preferable single steel pieces as it is easier to manoeuver for manual handling, particularly onboard a moving vessel. The length of the chain can also be customized to meet the weight requirements of the specific mooring. Note that cut-to-order chain pieces can be more expensive to source than scrap metal.

One caveat is that in high-current areas with coarse substrate, a combination of sand blasting and corrosion can reduce the lifespan of a chain anchor. Refer to section 2.2.2 for more information regarding metal corrosion. Alternatively,chain anchors can move in a way that absorbs shock energy imposed on the mooring by currents and waves, making it a good option for high-current areas (see case study 6 or table 1 for more details). Chain can also be shackled straight into the lug of a receiver or acoustic release, eliminating the need for an anchor strop.

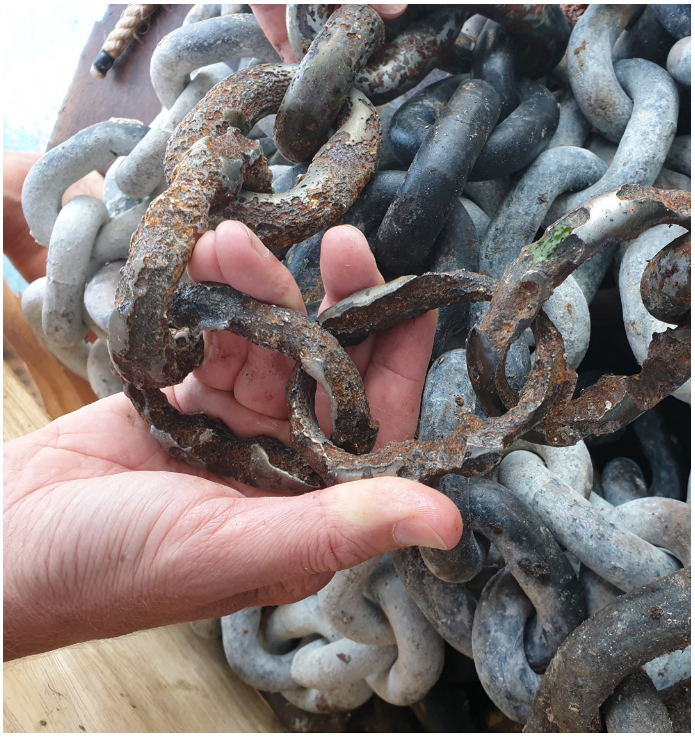

Figure 3: Chain corrosion.

2.1.5 Combination Anchors

To increase anchor weight, more than one anchor can be combined together for each mooring. This can look like multiple loops of scrap chain linked together or several concrete anchors connected with ropes (see section 2.2.2). Avoid mixing different metal types, however, as this can increase the risk of galvanic corrosion (see section 2.2.2.3).

The benefit of a multi-piece anchor is increased surface area on the seabed, reducing movement and adding redundancy. This additional surface area can be useful if grappling is the planned recovery method (see section 3.3).

Table 1: Anchor summary

Anchor	Suitability	Pros	Cons
Pre-existing structure	Shallow water locations, where hydrophone is unobstructed.	Relatively cheap, long lasting, no waste left behind.	Location limited, needs to be serviced by divers or snorkelers.
Star picket in reef	Shallow water, rocky or coral reef. Suitable for smaller receivers.	Relatively cheap, long lasting (3+ years), low manual handling.	Location limited, needs to be diver-serviced. Requires skilled divers to install the star picket for its initial deployment.
Star picket in concrete block (see case study 1)	Shallow water, soft substrate (e.g. sand). Suitable for smaller receivers.	Mooring can be recovered by divers, is long lasting and the receiver can be easily detached for servicing, then reattached.	Manual handling for deployment and recovery can be challenging, and requires skilled divers. Mooring can tip over or flip in high-current environments.
Mastaba - custom, low profile, concrete mould (see case study 1)	Shallow water, soft substrate (e.g. sand). Can be custom designed for any size receiver.	Mooring can be recovered by divers, is long-lasting and the receiver can be easily serviced leaving the anchor in place.	Manual handling for deployment and recovery can be challenging. Mooring can become buried in soft-sediment environments.

Anchor	Suitability	Pros	Cons
Concrete mooring block	Any depth, soft substrate.	Can be moulded to the required shape for the environment. Relatively cheap.	Concrete anchors need to be compensated with larger sizes or volumes to compensate for inherent buoyancy. Manual handling and recovery can be challenging. Deployment from a vessel can cause excessive load force on acoustic release lugs leading to equipment failure. (See section 3.2 Deployment methods).
Single piece metal	Any depth, soft substrate.	Relatively cheap. Can have casted options (like disc anchors) or utilise scrap.	Manual handling can be challenging, not always suitable for high current environments. Deployment from a vessel can cause excessive load force on acoustic release lugs leading to equipment failure. (See section 3.2 Deployment methods).
Heavy link chain	Any depth, soft substrate.	Absorbs some movement preventing the mooring from flipping in current. Easier for manual handling than single-piece steel.	Possibly more expensive than scrap metal, potential for chain links to fail if pitted/scoured.

2.2 Risers

In this document, the riser is defined as anything that connects a suspended acoustic receiver to its anchoring point. Below, the various riser options and their applications will be discussed.

2.2.1 Anchor lines

The anchor line creates an attachment point between the anchoring structure and the acoustic technology. This may be a connection to an acoustic release, or directly to an acoustic receiver if a separate release is not incorporated in the deployment.

Determining the length of your anchor line will be study-specific. When deploying acoustic telemetry equipment in areas with potential commercial fishery interference there are customizations that can be made to reduce the risk of mooring loss. For instance, a shorter anchor line and riser can help keep the instrumentation closer to the bottom, potentially away from midwater fisheries. A longer line will pose more environmental risk (ex: whale entanglements), introduce more drag, present more risk of fisheries interaction, and is more costly (more high-quality rope required). However, a long riser may be required if the acoustic receiver needs to be at a certain depth in order to collect detections of your target species, or for servicing and recovery. Risers should be of a length that ensure that they keep the acoustic receiver unit above the surrounding substrate (e.g. valley, boulder field, coral growth).

The anchor line must be strong enough to withstand the forces encountered during a deployment. The point of connection where the anchor line connects to the remainder of the mooring must have a strong enough load rating to survive the force of the anchor drop. Care should be taken upon deployment that the anchor is not dropped from exceedingly high off the water, to minimise the impact and avoid potential damage to the lug of an acoustic release receiver (see section 3.2.2).

When deciding on an anchor line, keep in mind the potential points of failure and how to mitigate them, as outlined in section 2.2.2. Commonly, either a rope or chain strop is used.

2.2.1.1 Rope strop

When using a rope strop to secure your mooring to your anchor, you must ensure that the rope used is durable enough to withstand the duration of deployment and any reasonably anticipated abrasions, stresses and strains on the mooring (e.g. current or wave force). Multi-filament rope designed for marine applications is generally recommended.

Variations of high-end ropes include double braid polyester with a high tenacity core, such as yacht braid, or ultra-high molecular weight polyethylene. Examples of these ropes can be seen in case study 5 and case study 4, respectively. The higher-cost ropes can often be reused and repurposed for multiple years due to their durability. This is a reduction of material waste that could benefit the carbon footprint of your project. However, these ropes are not likely to break during fisheries or marine animal interactions, which could cause vessel damage or entanglements. Using a polypropylene mooring line is a lower cost option and is most reliable when using larger diameters (20 mm+). While polypropylene ropes can be reused, they lose strength and reliability during extended deployments, and hence are less suitable over time and will need to be replaced more frequently.

2.2.1.2 Chain strop

Where a single-piece metal anchor is selected for a mooring, a chain strop may be an appropriate option. A chain strop is sturdy and eliminates the need for a polyester rope. An example of a commonly used design is an approximately 1.5 m length of 10 mm or 12 mm galvanised chain shackled to a steel beam, with the other end shackled to the lug, lower attachment point, of a receiver with an integrated acoustic release. Note that this can result in wear on the receiver lug, and this could cause ambient noise in high energy locations.

Having multiple pieces of metal and multiple connection points within a mooring, however, can introduce potential points of failure and if no swivels are used the twist caused by currents can lead the chain to break. Chain itself can also be vulnerable to corrosion (refer to section 2.2.2.3).

2.2.1.3 Stretch hose

When in high energy environments, the use of pliable materials like stretch hose for risers will cause less wear on the connection points, thus extending the longevity of a mooring. Stretch hoses are a higher-cost component, but have lower risk of biofouling due to their movement during deployments, are neutrally buoyant, and can reduce shock loads at potential failure points of a mooring (Spec Information, SafeMoor, n.d.).

2.2.2 Connection points and failure prevention

It is important to note that any hardware that is used in the anchor line should be kept distant from the hydrophone on the acoustic receiver, as the movement of the hardware can create noise and the interference can affect the detection recording performance. Rope does not generally pose this interference risk to your data collection, but does have other drawbacks such as the potential to chafe. Refer to section 3.2 for more details on how mooring connection points need to be considered during deployment planning.

2.2.2.1 Rope-only

If solely rope is used, it is important to minimise any points of weakness:

- Utilise **non-slip knots** that hold tension from both directions, for example:
  - A bowline: very commonly used.

    - An anchor bend: can be used to fasten the anchor line to the anchoring structure.
    - A sheet bend: recommended when attaching two ropes of unequal sizes.
    - A double fisherman's bend: very useful for securely tying two ends of a mooring line together, or two ropes of different sizes.
- Use **chafe guard or tape** to protect areas of rope that may experience any friction or abrasive force underwater (e.g. sections tied in a knot, or around metal components); and,
- Reinforce the knots by **splicing, taping or adding cable ties** around the tail ends. Any sharp edges of cut cable ties can be carefully filed down to reduce any potential abrasive force.

2.2.2.2 Combination rope and metal

Additional metal hardware can also be integrated into a rope strop, for example, steel thimbles can be spliced into the end of a line to provide a robust attachment point to the anchor, acoustic device, or float. Be aware that mooring lines can stretch under load and thimbles can work themselves loose over long deployment periods, so consider using cable ties to secure them to the mooring line. The addition of metal components to rope can also increase the potential for wear or damage to the rope during both the deployment and recovery.

2.2.2.3 Metal-only

The use of metal components into a mooring design can bring increased risk of galvanic corrosion or points of weakness. Caution must always be used when choosing metal hardware for deployments underwater, especially in seawater.

To mitigate the risk of metal mooring components failing due to corrosion during deployment, the following strategies are encouraged:

- Use metals that are more corrosion-resistant where possible, including galvanised steel, high-grade marine stainless steel (e.g. SS316), or titanium;
- Try to use products consistently from the same manufacturer where possible and when proven reliable. Products from different manufacturers may look the same, but may be different in composition with impurities that encourage galvanic corrosion and reduce the life of the mooring components.
- Avoid integrating less noble metals (e.g. aluminium) and avoid mixing metals wherever possible, to minimise the risk of corrosion through galvanization. If using less noble metals, plan to replace these components more frequently;
- Utilise sacrificial zinc anodes in combination with other metal hardware to guard against galvanic corrosion, particularly for long-term deployments;

- Check all metal mooring components for signs of corrosion before deployment and periodically throughout deployment if possible, particularly if the deployment time is >12 months;
- Protect the threads and pins of shackles with marine greases or lubricants, like lanolin grease, because corrosion will often occur here first;
- For long-term deployments, plan to replace anchor lines, star-pickets, chain and shackles prior to failure, based on diver or underwater camera observations where possible; and,
- Be aware of crevice corrosion, which occurs when metal is exposed to low flow and low oxygen environments and corrosion forms in any seams in the metal. To avoid crevice corrosion:
    - Avoid covering stainless steel components (e.g. with duct tape). Stainless steel can be quite vulnerable to crevice corrosion especially when partially covered, which creates a low oxygen micro-environment.
    - Working in silty or mudding bottoms can also cause conditions favourable for the formation of crevice corrosion, and it is possible that replacing metal parts with high-tensile strength rope might be preferable in these conditions to ensure the longevity of the mooring.
- As a secondary fail-safe, the pins of each shackle can be secured with a cable tie or cable wire to seize the shackle when the mooring is ready for deployment. However, be aware that metal cable wires can increase corrosion risk (see above).

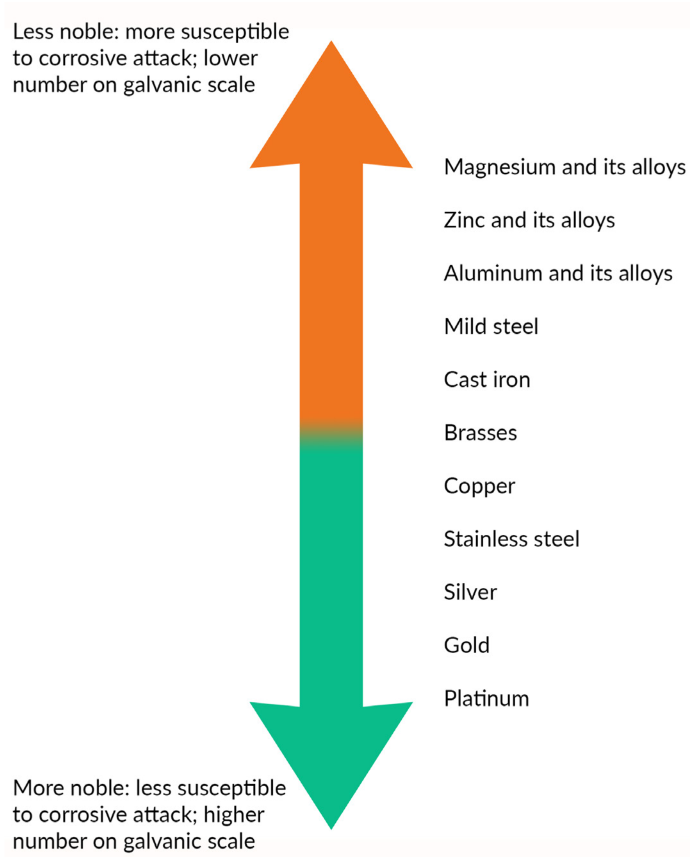

Figure 4: Corrosive and galvanic scale for potential mooring metals

It is recommended to return to your mooring for maintenance at least once every 12 months. Divers may be able to manually remove biofouling underwater without needing to recover the whole mooring. If deploying in deeper water, it may be prudent to factor in more floatation capacity (and corresponding anchor weight) to counteract potential biofouling weight. Be cautious, however, of adding significant surface area for biofouling to attach to. Increased buoyancy without significantly increased surface area is ideal.

There are antifouling pastes and paints that can be used to try and limit biofouling; however, traditional copper-based antifouling paint can be harmful to the surrounding environment and its use is now illegal in many jurisdictions. Silicone-based, biocide-free ‘fouling-release’ coatings are an option that may see an increased uptake in future. For now, the long-term effectiveness in a stationary acoustic mooring is relatively untested in the field, but shows potential as a viable, less-harmful alternative to traditional antifouling products.

Tape or sheer stockings can also be used around a receiver or release to allow for an easier removal of biofouling upon recovery, as long as they are not obstructing the hydrophone portion.

2.2.3 Release mechanisms and brackets

For moorings at depths greater than 30 m without surface access, an acoustic release mechanism integrated into the riser section of the mooring is an option for a full or partial recovery of the mooring. Some receiver models have built-in release mechanisms (refer to case study 3).

For receiver models that do not have built-in release mechanisms, it is possible to add a stand-alone acoustic release into the mooring. This is positioned above the anchor but below the receiver and below the floatation package, which ensures that both the release as well as the receiver are retrieved when the release mechanism is activated. From experience, the models which have a screw-in lug style have had best success, especially when battling biofouling over longer deployments. Pay attention to which release mechanism the desired acoustic release unit has to best prepare for maintenance needs of the mooring.

If the acoustic receiver does not have a built-in release mechanism, there needs to be an attachment line or hardware to connect the release and the receiver/floatation package to each other. In many cases, rope is used but metal hardware is also an option. For design purposes in this document, this integration is still considered part of the riser.

Purpose-built steel brackets are a reliable option and have been utilised in a range of environments and depths to attach either a separate acoustic release to a receiver or attach a rope canister to a mooring to allow for full anchor recovery (refer to case study 5). All the same considerations regarding galvanic corrosion and ensuring secure attachments as outlined in section 2.2.2 apply here as well.

Table 2: Riser summary

Riser type	Suitability	Pros	Cons
Rope strop	Any mooring.	Lightweight, easy to manoeuvre. Does not create noise interference.	Potential weak point with fraying and chafing
Chain strop	Sacrificial moorings, low flow environments.	No fray, no plastic.	Noise interference. Potential corrosion leading to failure over time.
Rope canister attachment	Recoverable moorings, depth determined by manufacturer.	Allows for anchor recovery.	Requires a steel bracket to attach to the rest of the mooring. Requires extra resources to build, and boat winch to recover. Extra complexity is introduced into the mooring increasing risk of failure.
Free mooring release	Any mooring, especially if not serviceable by diver.	Allows for deployment in deeper areas.	Tension load capacity, some latching mechanisms more susceptible to biofouling, increase in failure points for entire mooring.
Bracketed mooring release	Any mooring, especially if not serviceable by diver. High-energy environments requiring chain.	Allows for deployment in deeper areas that are not as accessible. Secure attachment location.	Heavy, may result in corrosion and failure over time with the use of metals, rigid.

2.3 Acoustic receiver

Choosing an appropriate, fit-for-purpose acoustic receiver is the single most important decision when trying to achieve the goals of your study. The choice of receiver is informed by both conditions in the desired study environment and by your study species and maintenance schedule. For extremely deep environments, the depth rating of the receiver may impact the receiver choice. Most acoustic receiver models have ample depth rating (generally 500 metres) for the great majority of acoustic telemetry study objectives.

The duration of the entire study, deployment timelines, maintenance schedules, cost of equipment and servicing, along with receiver protocols and programming need to align with your study objectives. A benefit of a less expensive receiver is the ability to purchase multiple units to create a multiple-mooring array. Receivers with shorter battery lives are suitable when working with easily accessible mooring locations but there are additional costs associated with frequent mooring maintenance. As noted previously, some receivers have built-in release mechanisms that can serve as an easy recovery method, but these receiver/release combinations are more expensive. There are also receiver models that have long-term batteries (3+ years) that require infrequent servicing and can be offloaded remotely using hydrophones and acoustic modems instead of recovering the unit for data retrieval. These are excellent options for large operations and maintenance budgets, however, biofouling will become a greater challenge.

The placement of the acoustic receiver in the mooring design is important. When mounting the receiver to a structure, should it be mounted with the hydrophone facing upwards in the water column, or downwards? How far off the bottom should the receiver be located? These questions are informed by the study species (benthic vs. pelagic species) as well as the risk of fisheries interaction (in what part of the water column do commercial trawlers operate in this region?), and the recovery method (diver recovery or acoustic release?). In any orientation, the receiver must be securely fastened to either the mooring or the riser. Care must be taken to ensure the hydrophone is fully exposed in the water column, and not “shadowed” by any mooring components. Different arrangements of hardware and cable ties are commonly used to secure the receiver. Where possible, custom floatation can be purchased which is moulded to fit the receiver inside, but these options are expensive.

In general, receiver choice is extremely important when deciding on a mooring design and both choice of receiver and mooring type is greatly impacted by study goals and budget.

2.3.1 Additional sensors

It is possible to integrate additional environmental sensors into your mooring design. Some sensors which measure environmental conditions that are important to the study animals such as temperature, salinity and other oceanographic variables are quite small and can be attached directly to the riser line using cable ties. If larger instruments need to be integrated, floatation for the mooring may need to be increased to provide additional lift to compensate for the weight of the instrument. The instruments should be included in the mooring line between the acoustic release and the floatation so that when the release is activated, they are recovered at the surface with the rest of the mooring.

Care should be taken to ensure that any additional instruments included in the mooring package do not interfere with the acoustic receiver. For example, other acoustic devices such as an Acoustic Doppler Current Profiler (ADCP) emit sonic pulses that can deafen the acoustic receiver while the ADCP is operating. Any instruments generating noise that could interfere with the detection of tags should be kept further away from the acoustic receiver, duty-cycled to minimize impacts on the amount of time an acoustic receiver can detect tags, or not co-deployed with an acoustic receiver.

2.4 Mooring floatation

Floatation used for your mooring has more than one purpose. Mooring floatation is used to keep equipment upright in its desired location and orientation to maximise omnidirectional detection capabilities for the receivers, but it is also used to bring the receiver to the surface for retrieval. It can also be an excellent sonar target to locate a subsurface mooring or, in the case of surface buoys, can mark your deployment station.

2.4.1 Surface floats

In some cases, a surface buoy attached by a rope to the receiver and anchor can be used as the floatation. This buoy is typically easy to locate for servicing and retrieval of a deployed receiver. However, such moorings are also at high risk of tampering or vandalism by third parties which can compromise the integrity of the study. In high energy areas over prolonged deployments the buoys can also break free of their mooring line due to chafing, resulting in loss of the rest of the equipment. Surface buoys and lines can also pose a hazard to navigation due to collisions or entanglement in ship propellers, and having rope span from the seafloor to the surface can pose an entanglement risk for marine animals in the area, especially whales.

2.4.2 Subsurface floats

Subsurface buoys will suspend the receiver in its desired orientation in the water column. They require that sufficient anchor weight be provided to sink the float and keep the entire mooring on its desired station for the duration of the deployment. When attaching your floatation above the hydrophone of telemetry equipment (a topside floatation design), ensure that you use a riser length that leaves enough space between the float and the hydrophone to avoid shadowing from the float which can interfere with mooring equipment communications as well as detection efficiency. Ensure that the depth rating for your float is suitable for your application and deployment.

Floatation devices are generally either hollow or made of syntactic foam, and the best type for your mooring will be determined by the depth of the deployment and your budget. At high pressure in deep deployments, it is recommended to use syntactic foam floats that do not compress and will remain buoyant under pressure. By contrast, hollow floats under pressure are susceptible to collapse leading to water breach and sinking. Hollow floats are often less expensive which make them attractive, and they may be suitably reliable for other conditions. Note that any damage to a hollow float (ship collision, damage during deployment, strong wave action) can cause your float to crack and sink. Adding redundancy with > 1 hollow float per mooring may be a good risk management strategy in certain environments. Polystyrene floats are not recommended for use with acoustic moorings because they can absorb water over time, reducing the floats buoyancy. In addition, it is difficult to remove encrusting organisms from polystyrene, and floats of this material can easily become weighed down with biofouling to the point that they sink.

The most common floatation design is a ball float (see case study 3), which generally has a hole through the middle to be used for attachment. These come in a variety of sizes and materials and can be found at many fishing supply stores. It is possible to obtain custom acoustic receiver floatation packages which are designed with specific fasteners to hold the acoustic receiver inside the float (see case study 4). These can range in complexity and price from a simple 3D-printed "v-cup" attachment (see case study 3, figure 8b for a diagram) within a commercial-grade ball float to a custom trawl-proof syntactic foam float designed specifically for one acoustic receiver model. If a custom float is too expensive for your budget a ball float can be an affordable substitute.

The presence of currents and their velocities also should be considered when choosing a floatation design. In very dynamic regions, where currents are strong, the shape of the float can play a role in the performance of the mooring and receiver, by affecting the receiver's orientation in the water column and/or through the generation of flow noise. Refer to case study 6 for a real-life example and application.

The alternative to a topside float is a float collar. Float collars, while usually more expensive, have the benefit of sitting below the hydrophone of a receiver, eliminating any potential shadowing effect caused by a top float. Some more costly custom floatation packages are designed to be "trawl resistant" for potential ship activity or collision. This expense can be avoided if researchers focus the study location on a site less impacted by fishing and adjust research questions accordingly.

Table 3: Floatation summary

Float type	Suitability	Pros	Cons
Syntactic foam topside float	Low volatility, long or short term.	High depth rating. Little failure from pressure changes. Does not sink if damaged. Versatile to many receiver options.	Can be expensive.
Hollow topside float	Short term, low volatility environments.	Cheap.	Can fill with water and sink if cracked. Compresses under pressure.

Float type	Suitability	Pros	Cons
Collar floats (syntactic foam)	Receivers with collar floats and an integrated acoustic release. Any depth, current or substrate type.	No shadowing of the hydrophone. Durable and robust, rated up to 750 m depth. Easy to clean and attach, allowing for quick turnaround for redeployment. Cannot be punctured, compressed or separated from the receiver during deployment.	More expensive than traditional top floats. Specific to one receiver model.
Polystyrene topside float	Very short term and shallow deployment.	Budget friendly.	Unreliable. Easily biofouled. Fish consumption of float, introducing marine plastics. Compress under pressure.
Hollow hardball collared float	Suitable for short term, shallow deployments.	Reduction in full mooring size. Low profile.	Hollow floatation susceptible to cracking or breaking under change of depth pressure. These are often designed specifically for one unit, therefore not transferable.

3 Mooring maintenance considerations

Recommended practices for mooring deployment, recovery and maintenance include the following, to be expanded upon below:

- Prioritise personnel safety at all times.
- Before deployment, carefully document receiver serial numbers to be deployed on each station.
- Take as accurate a GPS waypoint as possible, and carefully document the deployment coordinates.
- Take extra consideration when deploying a mooring with a long riser, heavy anchor or involving divers.
- Plan the mooring recovery strategy and contingency options in the early stages of the study (well before deployment).

3.1 Safety considerations

Best practices for mooring deployments are based upon recommendations that improve safety, efficiency, and success of the mooring. The process begins with operating within vessel capabilities. This includes ensuring missions are not exceeding the weight capacity rating, or personnel capacity, of the service vessel or any of its lifting equipment. For large deployments, you may need to plan for multiple trips to deploy all moorings if the sum of all anchor weights is too great to load onto the vessel at one time. Similarly, the vessel must be appropriately equipped to access the study site (inshore and shallow vs. offshore and exposed) and meet all nautical safety standards for the region. The more components that are involved in a mooring design, the more complicated the deployment process can be. Always ensure personnel are trained, wearing appropriate Personal Protective Equipment (PPE) and are practicing safe manual handling, and eliminate any entanglement risks.

3.2 Deployment methods

When deploying a subsurface mooring from a vessel, there are some standard protocols that need to be followed. As the vessel arrives at the deployment location, the crew should prepare the mooring by recording the coordinates of the mooring site and the time and date of deployment, fastening all final connections (hardware or knots) and recording all serial numbers from the components of each mooring assemblage. Careful metadata collection is crucial.

The vessel master will need to account for prevailing conditions. Good communication and planning amongst the field team and vessel master is important to prevent deployed moorings becoming tangled with the propeller or other parts of the vessel.

Once on station, the mooring floatation package can be put overboard first, so that it trails behind the vessel and pulls the riser taught. When this is accomplished, the release may be placed overboard as well, to trail along the vessel. Ensure the speed of the vessel is slow enough that there is no damage to the release occurs through banging into the vessel. When finally ready to deploy, the anchor should be pushed from the vessel (or lowered from its lifting mechanism) into the water and released to pull the rest of the mooring component down with it. It is recommended to use a vessel with a lifting device (e.g. winch) to deploy anchors which exceed your region's safe lifting capacity. Avoid dropping the mooring from high points on the vessel.

A final GPS waypoint should be taken at the site at the point that the anchor was deployed.

Special deployment considerations are outlined below.

3.2.1 Long riser considerations

When deploying a mooring with a particularly long riser or anchor line (e.g. a deepwater mooring with 100m or more of riser length), care needs to be taken to ensure that the mooring does not get tangled during deployment. While the vessel is several hundred meters away from the deployment site, the vessel should slow down, and the floatation package should be deployed and allowed to trail behind the vessel. The riser should be gradually fed into the water (including the release portion) with care taken to ensure the line remains taught and away from the vessel's propellers. When the entire riser and anchor line are taught and deployed, then the vessel can manoeuvre to the deployment station and the anchor can be dropped, sinking the mooring. For safety purposes, having appropriate lifting mechanisms on board (e.g. a winch or boom) to be able to lift the weight of the anchor safely is advised.

3.2.2 Extremely heavy anchor considerations

If heavier anchors are required (90 kg or more) the best method to deploy the anchor is to lower it to water-level using a lifting device (e.g. a ship's hydraulic crane) in order to avoid causing undue strain to the mooring attachments by dropping the anchor from a height. This will require a vessel with adequate lifting/maneuvering capability. When using extremely heavy anchors, the maximum tension force for the material connected to your retrieval mechanism has a snap limit that can result in failure of the connection point. The float and equipment should be in the water at time of anchor lowering, using the vessel lifting device to lower the anchor in the water. Ensure that the anchor weight, in addition to the force of deployment into water, does not exceed the snap force of the connection point by assessing the load force rating on the connection points of the mooring.

3.2.3 Diver deployment considerations

If heavier anchors are required (90 kg or more) the best method to deploy the anchor is to lower it to water-level using a lifting device (e.g. a ship's hydraulic crane) in order to avoid causing undue strain to the mooring attachments by dropping the anchor from a height. This will require a vessel with adequate lifting/maneuvering capability. When using extremely heavy anchors, the maximum tension force for the material connected to your retrieval mechanism has a snap limit that can result in failure of the connection point. The float and equipment should be in the water at time of anchor lowering, using the vessel lifting device to lower the anchor in the water. Ensure that the anchor weight, in addition to the force of deployment into water, does not exceed the snap force of the connection point by assessing the load force rating on the connection points of the mooring.

3.3 Recovery methods

The recovery method should be decided well before the mooring is deployed. The first question that should be answered is which portions of the mooring will be recovered.

3.3.1 Surface buoy recovery

If your mooring included a surface buoy, fastening to an existing marine structure (e.g. wharf), or a line attached to shore (common in riverine areas) then the recovery method may involve simply hauling on the attachment point to retrieve the instruments for servicing. The logistics will vary depending on the specific attachment method that was employed.

3.3.2 Sacrificial anchors

Many moorings are designed with sacrificial anchors and acoustic releases. This allows recovery of all portions of the mooring except the anchor and some of the anchor line/attachment points. This is a method often used in deeper and more volatile waters where diving is not possible and may be the preferred method in offshore areas.

Remotely operated acoustic release mechanisms require specialised equipment to operate (i.e. a deck-top box and hydrophone), therefore the purchase of this equipment will need to be factored into the study plan and budget.

3.3.3 Recoverable anchors on acoustic release

It is possible to configure moorings so that all portions including the anchor can be recovered. This is accomplished by having a remotely triggered acoustic release in the design, as well as a canister of spooled or wound rope with one end connected to the riser section of the mooring, and the other tied into the anchor. When the riser reaches the surface, the rope can be connected to a vessel winch or other lifting mechanism to retrieve the anchor.

Rope canisters for recoverable moorings can either be self-built or purchased from a manufacturer. When building or assembling a rope canister, ensure to use appropriate rope with minimal friction and heavy durability. Refer to section 2.2.1.1 for more information.

3.3.4 Diving

Snorkeling or diving are often the preferred recovery methods in tropical, coastal regions and allows for recovery of all portions of the mooring (including anchor) in many cases.

Thorough dive planning is essential. Consult with a dive safety officer responsible for operations in the study area to ensure the dive plan is in accordance with relevant standards. Plan conservatively and actively manage diver fatigue. Ensure all divers are adequately qualified, experienced and comfortable with the work, whether it is retrieving or deploying an entire mooring, or just the receiver. Consult with others who have experience in the work and the study environment, at the planning stage.

It is also important to take prevailing conditions into consideration, including but not limited to; tides, currents, visibility, swell and water temperature. Adjust or postpone the dive plan if needed.

3.3.5 Grappling

Grappling to recover a mooring requires entangling them by dragging grappling gear behind a vessel over the position of a mooring. This can allow for recovery of the entire mooring including the anchor, but one should be mindful of the anchor weight. The heavier the anchor, the larger the vessel you will require to recover your mooring.

This process can be very time-consuming and expensive in ship time as it may take many passes over a particular mooring to entangle it. If the grappling effort is attempting to hook a bottom-mounted object, the repeated dragging efforts will likely cause some disturbance to the seabed in the area around the receiver. If there are sensitive benthos present, this recovery method will not be suitable. If this is the recovery method of choice, the mooring design can be altered for easier entanglement. An example would be to include two anchors, separated by rope/chain along the seafloor which provides a larger target for grappling. Note that if a grapple line is used, GPS coordinates need to be taken of both anchors to facilitate grappling.

3.3.6 Underwater ROV

If access to a remotely operated vehicle (ROV) can be secured, there is potential to recover your acoustic receiver moorings using this machine. The ROV should be equipped with some type of manipulator arm that can either 1) feed a line through the mooring and run the line back to the vessel, 2) hook a surface line to an attachment point on the mooring or 3) cut the mooring loose with a cutter-arm attachment. In cases 1 and 2 the anchor can also be retrieved, but in case 3 the anchor will remain on the seabed and the receiver will return to the surface. Recovery via ROV is an expensive recovery method requiring specialized personnel, equipment, and vessel charters. This recovery method is currently most often used as a last resort to recover moorings where the acoustic release mechanism has failed.

4 Decision tree

In the next section, these guiding questions will be addressed in real-life deployments with high success rate of telemetry efficacy, safe deployment and successful recovery. The case studies can be used as a control for the mooring design choices - these are not the sole option, but options that have been tested.

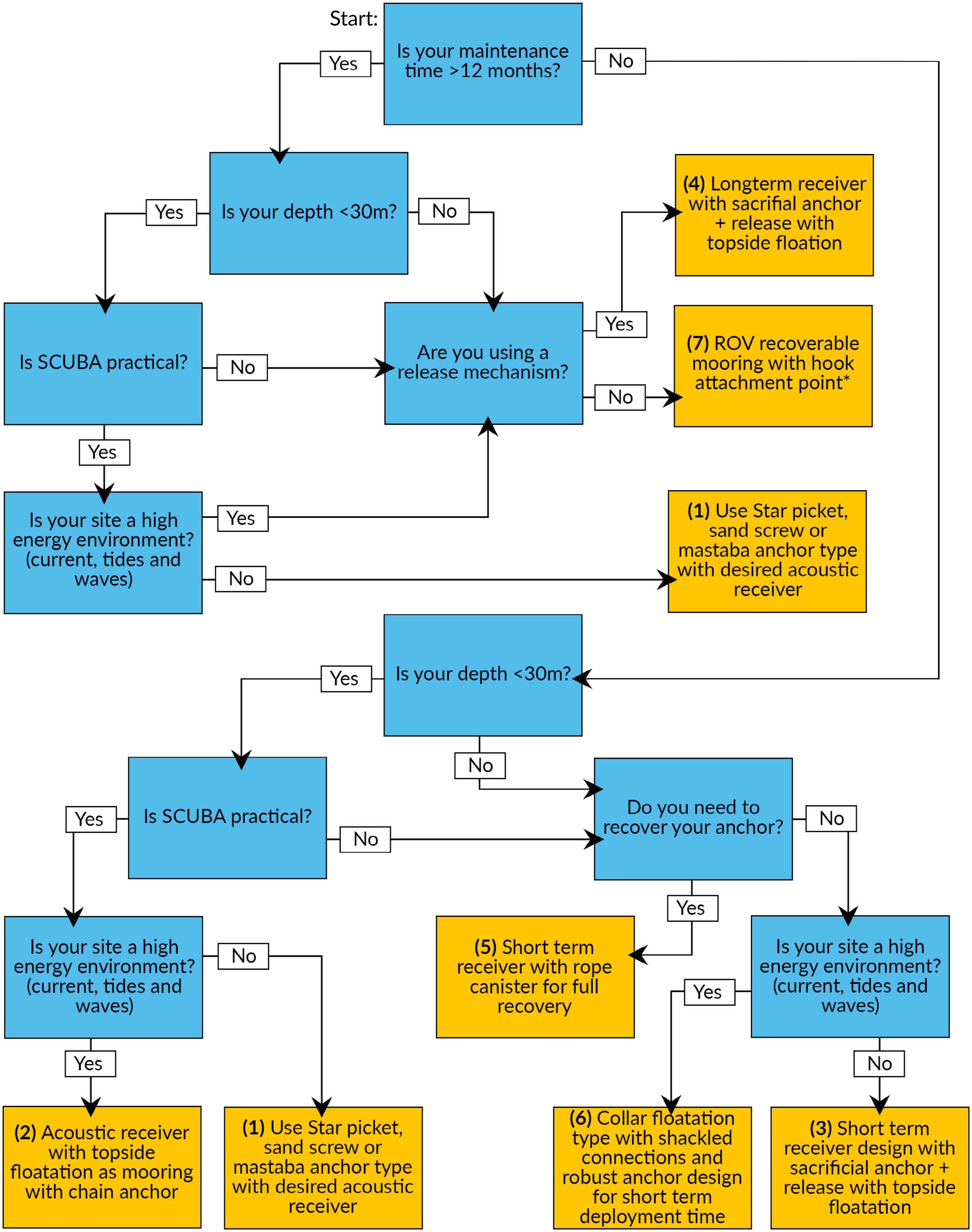

Figure 5: Mooring design decision tree. Associated case studies by number are presented below, where available.
* no case study available, see Appendix 1 for labeled graphic.

5 Case studies

Six real-life cases of tested and successful mooring designs are analysed below. By using the guiding questions and the results from the decision tree, the conditions of each of these cases are described.

Case study 1

Study characteristics: The deployment depth is less than 30 metres and is acceptable for SCUBA practice. The area is not considered a high energy environment. See figure 5, option 1.

Location: Mid-north coast, NSW, Australia.

Deployment method: Divers.

Recovery method: Divers.

Deployment duration: Planned for up to 10 years, depending on the lifespan of the receiver. Receivers may be recovered and redeployed separately from the mooring.

Maintenance schedule: Remote offload every 12 months between deployment/recovery, periodic inspection by divers as required.

Figure 6a: Photo of mooring design decision tree option 1 example case study 1.

Option 1 (Fig. 6b)

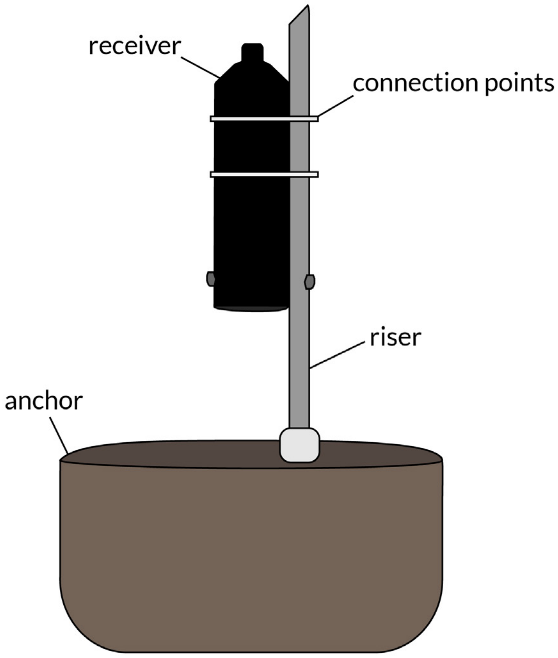

Figure 6b. Mooring design decision tree option 1.

Table 4: Mooring design decision tree option 1, case study 1, figure 6a and 6b.

Component	Method	Manufacturer details	Notes
Anchor	Concrete block or 'mastaba', with an attached PVC pipe that houses the receiver.	NA.	Concrete block was made by the IMOS technical team, but a similar design can be duplicated with pouring concrete.
Anchor line and connection points	NA.	NA.	NA.
Riser additions	NA.	NA.	Mooring is serviced by divers.
Acoustic receiver	This example uses a long term dual channel unit with 5-10 year battery, but could be easily manipulated for a smaller receiver.	Innovasea VR4-UWM receiver using 69 kHz and 180 kHz channels. Other receiver units can be used with suitable adaptations.	Requires yearly data offload using hydrophone operated from the vessel.
Floatation	NA.	NA.	Mooring is serviced by divers. Divers may utilize lift bags to bring the mooring anchor block to the surface when required. The receiver unit can be removed from the anchor block and brought to the surface by divers if required.

Case study 2

Study characteristics: Deployment location is less than 30 m deep and is suitable for SCUBA divers. Substrate is soft sand and the area can experience current and wave force. See figure 5, option 2.

Location: South coast, NSW, Australia.

Deployment method: From vessel.

Recovery method: Divers.

Deployment duration: Approximately 3 years. Mooring components should be inspected by divers annually and replaced prior to failure. Receivers may be recovered and redeployed separately from the mooring.

Maintenance schedule: Receiver recovered and redeployed by divers annually, independently of the rest of the mooring.

Option 2 (Fig. 7)

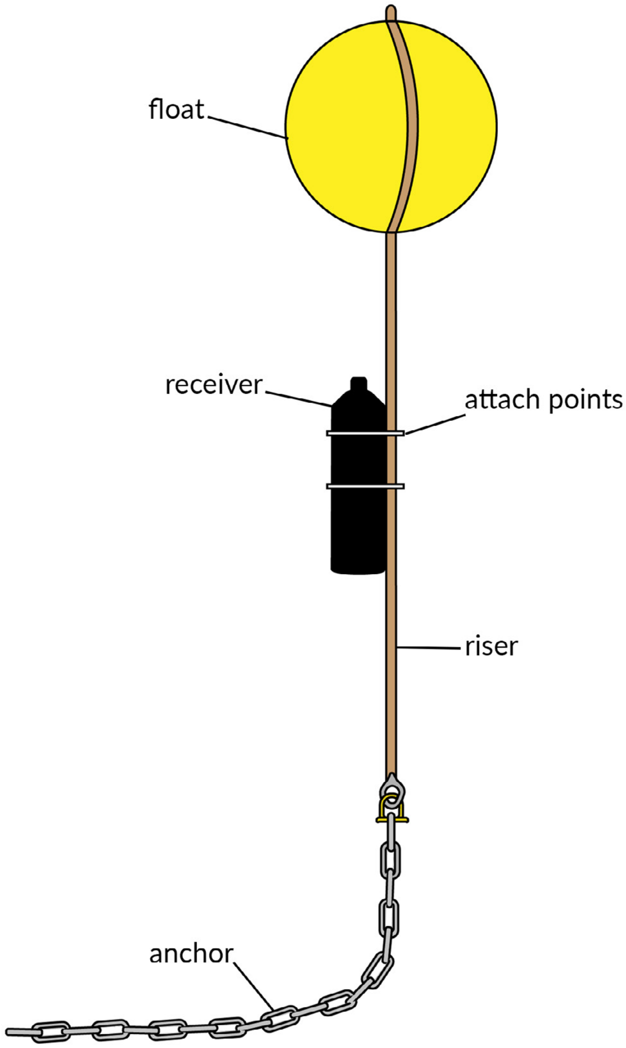

Figure 7: Decision tree option 2 for case study 2.

Table 5: Mooring design decision tree option 2, case study 2, figure 7

Component	Method	Manufacturer details	Notes
Anchor	~3.5m of 24mm link steel chain, weight ~44kg.	Purchased from local industrial lifting equipment supplier.	Chain should be checked every time the mooring is dived.
Anchor line and connection points	20 mm diameter polypropylene mooring line. Galvanized steel thimble spliced into the bottom of the line. Large steel shackle attaches a chain to the mooring line through the thimble.	Local rope supplier. Shackles purchased from local industrial lifting equipment suppliers.	Mooring components should be checked every time the mooring is inspected.
Riser additions	NA - divers.	NA.	Distance between receiver and float should be approximately 2 m to avoid shadowing the hydrophone, affecting detection efficiency.
Acoustic receiver	69 kHz unit with 12 months battery life and no integrated release. Connected to the mooring line with cable ties.	In this practical example, an Innovasea VR2W, however any type of receiver unit with appropriate fastening mechanisms works.	Receiver battery life is shorter than expected life of the mooring.
Floatation	Hard plastic float, 7 dm312.5 kg buoyancy, working depth 300 m.	Fishing product supplier, based in Australia.	Important to inspect the float for damage to ensure it will last the length of deployment. Divers may remove biofouling from the float during annual inspections.

Case study 3

Study characteristics: Deployment location is in a brackish estuary that is approximately 30 meters in depth, but generally not suitable for diving. Less than 12 month deployment and biofouling is a prominent issue. See figure 5, option 3.

Location: Bras D'Or Lakes, Nova Scotia, Canada.

Deployment method: From vessel.

Recovery method: Acoustic release.

Deployment duration: Approximately 12 months.

Maintenance schedule: Floatation Package recovery every 12 months to clean and refurb before redeployment.

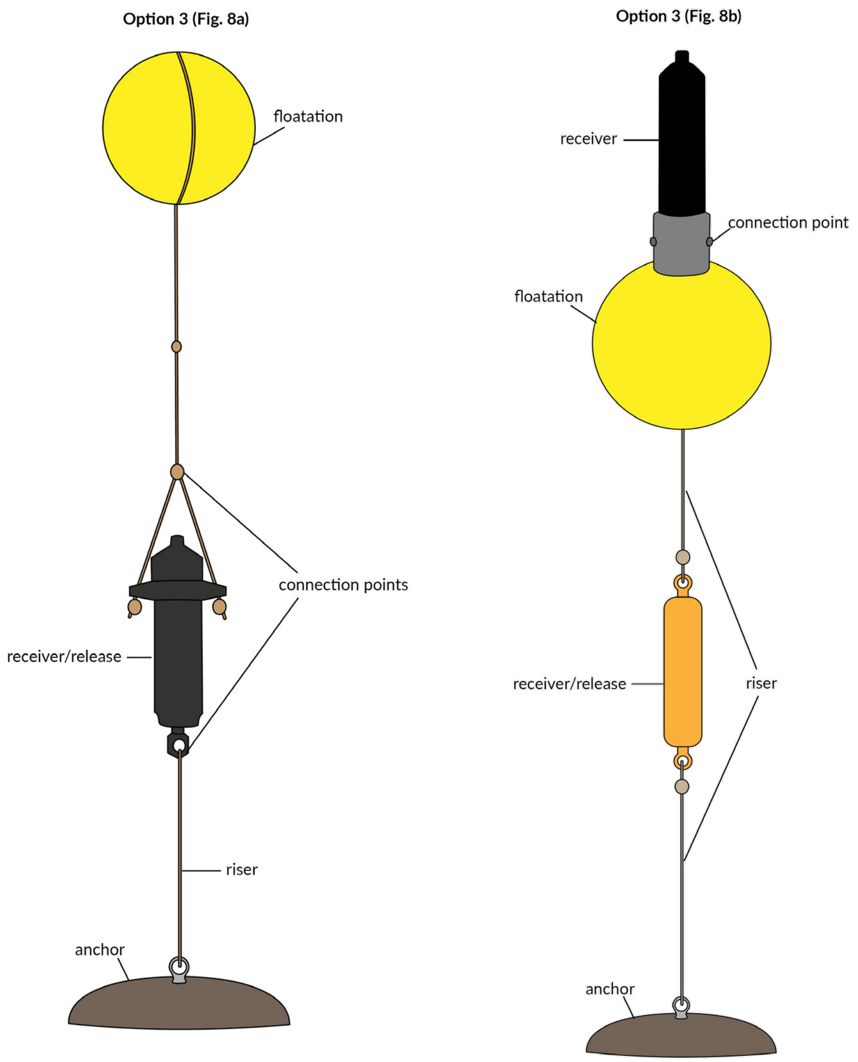

Figure 8a and 8b. Decision tree option 3 for case study 3 (two configurations).

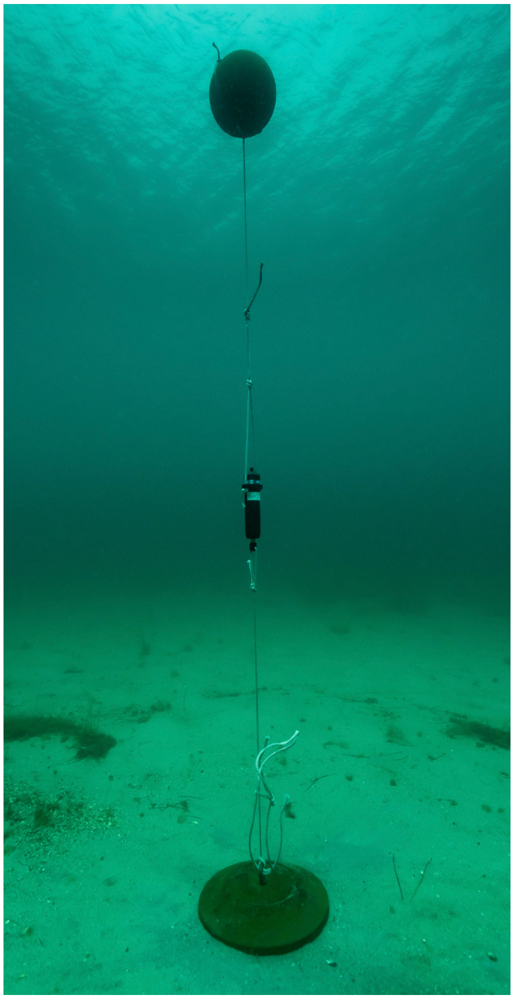

Figure 8c: Photo of decision tree option 5 for case study 3. Photo by Nicolas Winkler Photography, courtesy of the Ocean Tracking Network

Table 6: Mooring design decision tree option 3, case study 3, figure 8a, 8b and 8c

Component	Method	Manufacturer details	Notes
Anchor	90 kg anchor plate.	Ironcast fabricators with a 127 mm diameter, 190 mm long eye bolt for connection, lock washer and threaded nut.	
Anchor line and connection points	High strength, low stretch, 12 strand rope, anchor bend knot tied at eye bolt connector. Bowline tied around release nut of acoustic receiver/release combo.	Dyneema rope - 79 mm.	
Riser additions	Release built into acoustic receiver, or stand-alone acoustic release paired with receiver.	In this practical example, an Innovasea VR2AR 69 kHz acoustic receiver with release was used, but any receiver type with the same capabilities is suitable.	
Acoustic receiver	Combination acoustic receiver and release model. Has the benefit of minimizing the size of mooring.	Acoustic receiver is outfitted with release.	Has location on either side of the unit to feed 79 mm rope and secure with granny knot on either side.
Floatation	Syntactic foam float with a through-hole in the middle, 11.8 kg buoyancy, depth rated to 750 m. 3D-printed “v-cup” can be added to secure a receiver with a bolt through the plastic, and tied with a knot through the hole of the floatation (Figure 8b).	Deepwater buoyancy.	Use a secure loop knot (like a sheet bend) tied onto itself to loop through the center of the float and feed down to a top connection point of the receiver.

Case study 4

Study characteristics: This mooring design is used for long term deployments in water greater than 30 meters. The robust anchor is sacrificial due to the depth and timeline of deployment. See figure 5, option 4.

Location: Nova Scotia Continental Shelf, Canada

Deployment method: From vessel.

Recovery method: Acoustic release

Deployment duration: Approximately 5 years.

Maintenance schedule: Offload using hydrophone or glider method annually. Recovery at end of battery life for acoustic release.

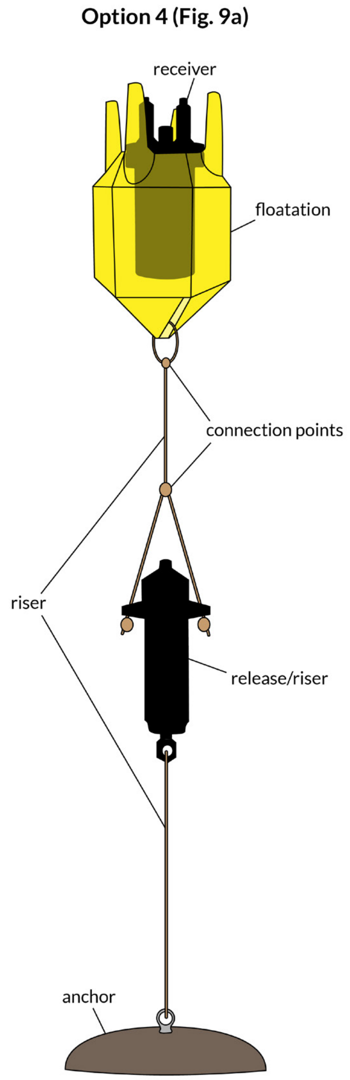

Figure 9a: Decision tree option 3 for case study 4.

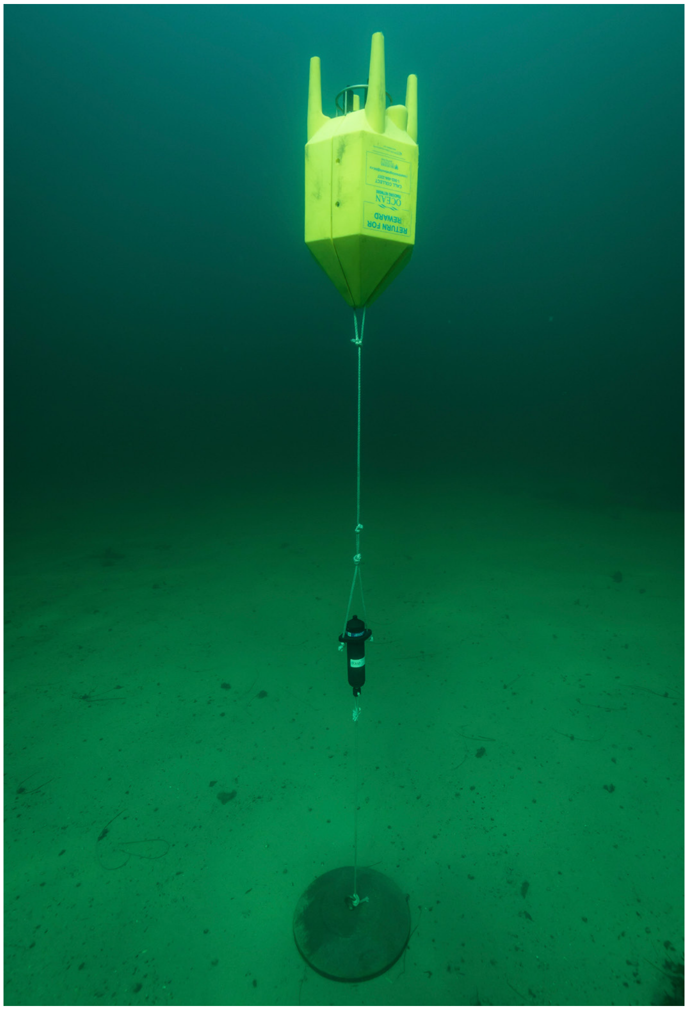
Figure 9b: Photo of mooring design decision tree option 3 for case study 4. Photo by Nicolas Winkler Photography, courtesy of the Ocean Tracking Network

Table 7: Mooring design decision tree option 4, case study 4, figure 9a and 9b

Component	Method	Manufacturer details	Notes
Anchor	90 kg metal plate with galvanized eye bolt.	Ironcast fabricators with a 127 mm diameter, 190 mm long eye bolt for connection, lock washer and threaded nut.	Pieces of scrap metal have been used in the past with areas for anchor line attachment added after sourcing. Focus is a robust weight for longer term.
Anchor line and connection points	High strength, low stretch, 12 strand, sinking rope.	Dyneema rope - 79 mm.	Anchor bend used at connection point for anchor; bowline used for connection points on top and bottom of receiver.
Riser additions	Acoustic release with 5 year battery.	EdgeTech PORT MFE Push off Release transponder with depth rating of 3500 meters and 250 kg release load	Bowline used to connect acoustic release and float together from connection point.
Acoustic receiver	Long term dual channel unit with 5-10 year battery.	Innovasea VR4 UWM receiver using 69kHz and 180kHz channels, but any long-term mooring could work.	Requires yearly data offload using various hydrophone methods.
Floatation	Floatation collar.	Kintama Trawl-Resistant Float Collar designed for Innovasea VR4 filled with syntactic foam. Depth rated for 500 m.	

Case study 5

Study characteristics: This mooring design is used for short term deployments in water that is greater than 30 meters and low ocean energy. The anchor must be recovered along with the rest of the mooring. See figure 5, option 5.

Additional notes: This is an alternative for deployments in strict Marine Protected Areas, where the disturbance from the deployments cannot permanently affect the seabed. In this case, recovery systems which allow for complete recovery of the anchor are beneficial.

Location: Ningaloo, WA, Australia.

Deployment method: From vessel.

Recovery method: Recoverable anchors on acoustic release.

Deployment duration: Approximately 12 months.

Maintenance schedule: Full mooring recovery every 12 months. Mooring components may be reused for future deployments, depending on condition.

Option 5 (Fig. 10a)

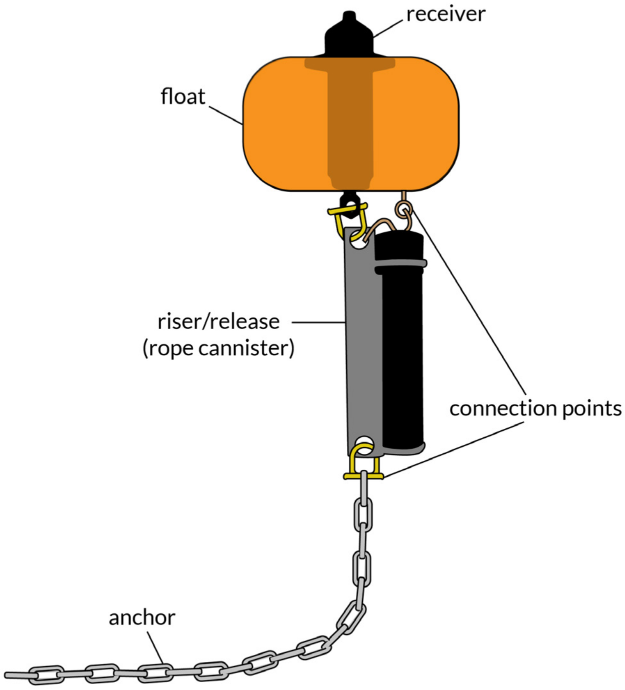

Figure 10a: Decision tree option 5 for case study 5.

Figure 10b: Photo of decision tree option 5 for case study 5.

Table 8: Mooring design decision tree option 5, case study 5, figure 10

Component	Method	Manufacturer details	Notes
Anchor	~3.5 m of 24 mm link steel chain, weight ~44 kg.	Purchased from local industrial lifting equipment supplier.	Scrap metal or rocks of a similar weight (with a suitable attachment point) could be utilized instead. A vessel with a winch is required to recover the anchor.

Component	Method	Manufacturer details	Notes
Anchor line and connection points	No anchor line, anchor chain is shackled directly to the base of the bracket with a 20 mm galvanized steel Dee shackle.	Purchased from local industrial lifting equipment supplier.	NA.
Riser additions	Acoustic release integrated within the receiver model. 16 mm galvanized steel Dee shackle connects the release lug to a purpose built steel bracket. Steel bracket holds a pvc 'can' containing wound rope, length ~1.5x the deployment depth. Rope ends are tied to the bracket and the float. Rope is a high tenacity, double-braid polyester sinking line.	Shackles purchased from local industrial lifting equipment suppliers. Steel brackets custom built by local steel fabricators.	The length of rope required will depend on the deployment depth. A conservative approach is a ratio of 2:1 for the rope length to depth, to counteract the effect of current, tide, swell and wind on recovery efforts. A ratio of 3:1 may be more beneficial in areas of medium to high water movement. Contact the IMOS team for more information regarding building a rope can.
Acoustic receiver	69kHz unit with integrated acoustic release and 1-2 year battery life.	In this practical example, an Innovasea VR2AR receiver is used. Other units with built in release units are also suitable	For this example, the mooring requires recovery within 12 months, based on the limitation of the release mechanism and the receiver battery life.
Floatation	Float collar, 11.8kg buoyancy, depth rated to 750m. OR Hard plastic floats with similar or greater buoyancy.	DeepWater Buoyancy for the float collar OR A fishing supply store.	Collar floats are likely to be more expensive than a top float, but they eliminate the float shadowing effect.

Case study 6

Study characteristics: This deployment location is in the highly volatile Bay of Fundy, home of volatile tide ranges >20 m generating tidal currents ~17 km/h. The mooring design calls for robust connection points and anchor weight. Specialized floats were manufactured in order to house the acoustic receiver units and maintain floatation in the high energy environment. Currents in the area can exceed 3 m/s and typical spherical ball floats create too much drag on the mooring connections during the high-flow tidal cycles, causing the acoustic receivers to drastically change orientation as the tides change. This drag has also resulted in the failure of the moorings as connection points fail from the strain. For floatation, a hydrodynamic Model A2 Streamlined Underwater Buoyancy Systems (SUBs) float is used, allowing the mooring to better move with the currents and reduce drag. See figure 5, option 6.

Location: Minas Passage, Nova Scotia, Canada.

Deployment method: From vessel.

Recovery method: Acoustic release.

Deployment duration: Approximately 6 months.

Maintenance schedule: Floatation Package recovery every 6 months due to high energy environment.

Option 6 (Fig. 11)

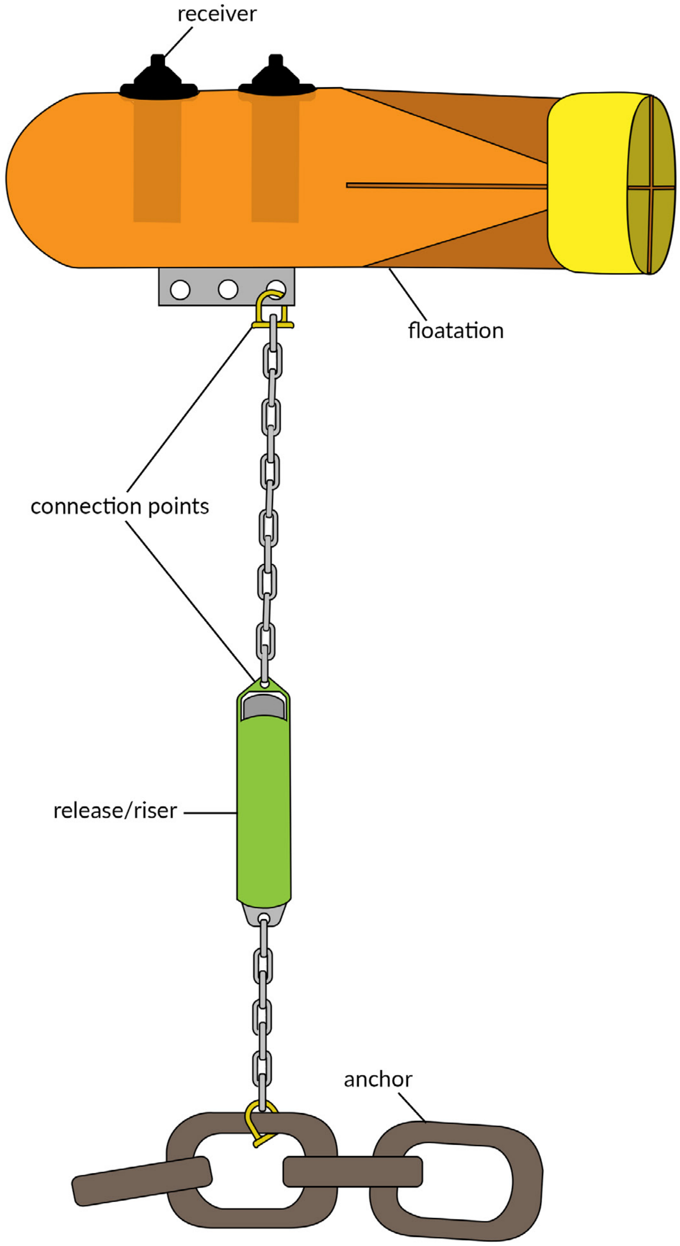

Figure 11: Decision tree option 6 for case study 6.

Table 9: Mooring design decision tree option 6, case study 6, figure 11

Component	Method	Manufacturer details	Notes
Anchor	365 kg boom chain.	Local metal manufacturers.	Need very heavy weight to compensate for extremely fast tidal currents.
Anchor line and connection points	Chain strop with shackles	Local fastener and rigging stores.	Check for chafing or failures more often than needed due to the high energy of the environment.
Riser additions	Requires heavy duty lift/load rating for buoyancy, high energy environment and weight for deployment with stretch hose for attachment to take some of the environment volatility shock.	Teledyne benthos R2K Acoustic release. Safe Moor stretch hose @ 2.5 m.	Stretch hoses absorb the shock of environment volatility.
Acoustic receiver	2 receivers operating on each deployment location/station.	For the needs of this study, VR2W 69 kHz HR2 (fine scale 2D/3D) 180 kHz.	
Floatation	Custom designed float collar with built in placement for desired receivers in bullet shape.	Model A2 Streamlined Underwater Buoyancy Systems (SUBs).	Bullet shape is more hydrodynamic, reducing impact and ambient noise for acoustic receivers.

6 Future considerations

This document is meant to serve as a starting point for designing a successful acoustic receiver mooring. The decision tree and associated case studies should provide some examples for operators to use as a guide when beginning new projects. Each study site is unique, and so adjustments from the provided examples will likely be needed. Stay flexible and rely on the principles outlined in the document throughout the planning process.

While accurate at the time of publishing, this document is meant to be reviewed and updated on a consistent basis by the authorship committee based at IMOS and OTN. There are innumerable ways to create successful acoustic receiver moorings and so readers are encouraged to contribute to this collaborative document by submitting mooring design examples. To contribute, please submit an Issue via the dedicated Github page https://github.com/ocean-tracking-network/OBPS-moorings. You will be required to provide the following information:

1. What is the specific use case for this mooring, and how does it fill a different need than those currently outlined in the document?
2. How many years have you used this mooring?
3. Include photos and diagrams.

On an annual basis, the authorship committee will review the submissions and amend the document. These best practices will be continually reevaluated as technologies and protocols change, and all attempts will be made to keep the document current.

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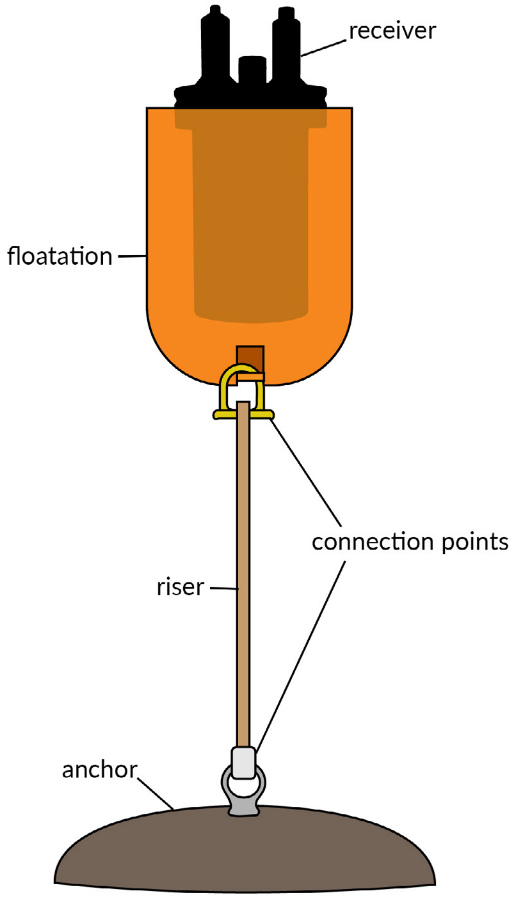
Lastly, the authors would like to thank the community members who provided valuable comments, edits and feedback on this document during the draft stage. Your knowledge and insights were greatly appreciated, and future contributions are welcome.

Appendix 1

Option 2



Option 7 from figure 5 decision tree

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